A Data Processing Method to Measure the Use of Manual Wheelchairs

Sharon Eve Sonenblum, PhD; Jayme Caspall, MS; Ricardo Lopez, MS; Stephen Sprigle, PhD, PT
Rehabilitation Engineering and Applied Research Laboratory, Georgia Institute of Technology

mobilityRERC

GOAL

The goal of this project was to develop and validate an approach to utilize wheel-mounted accelerometers to measure manual wheelchair use. The ability to study wheelchair use is necessary across a number of rehabilitation research topics including the outcomes of rehabilitation interventions, the long-term affects of wheelchair propulsion on shoulder health, and optimal wheelchair design.

DESIGN CRITERIA

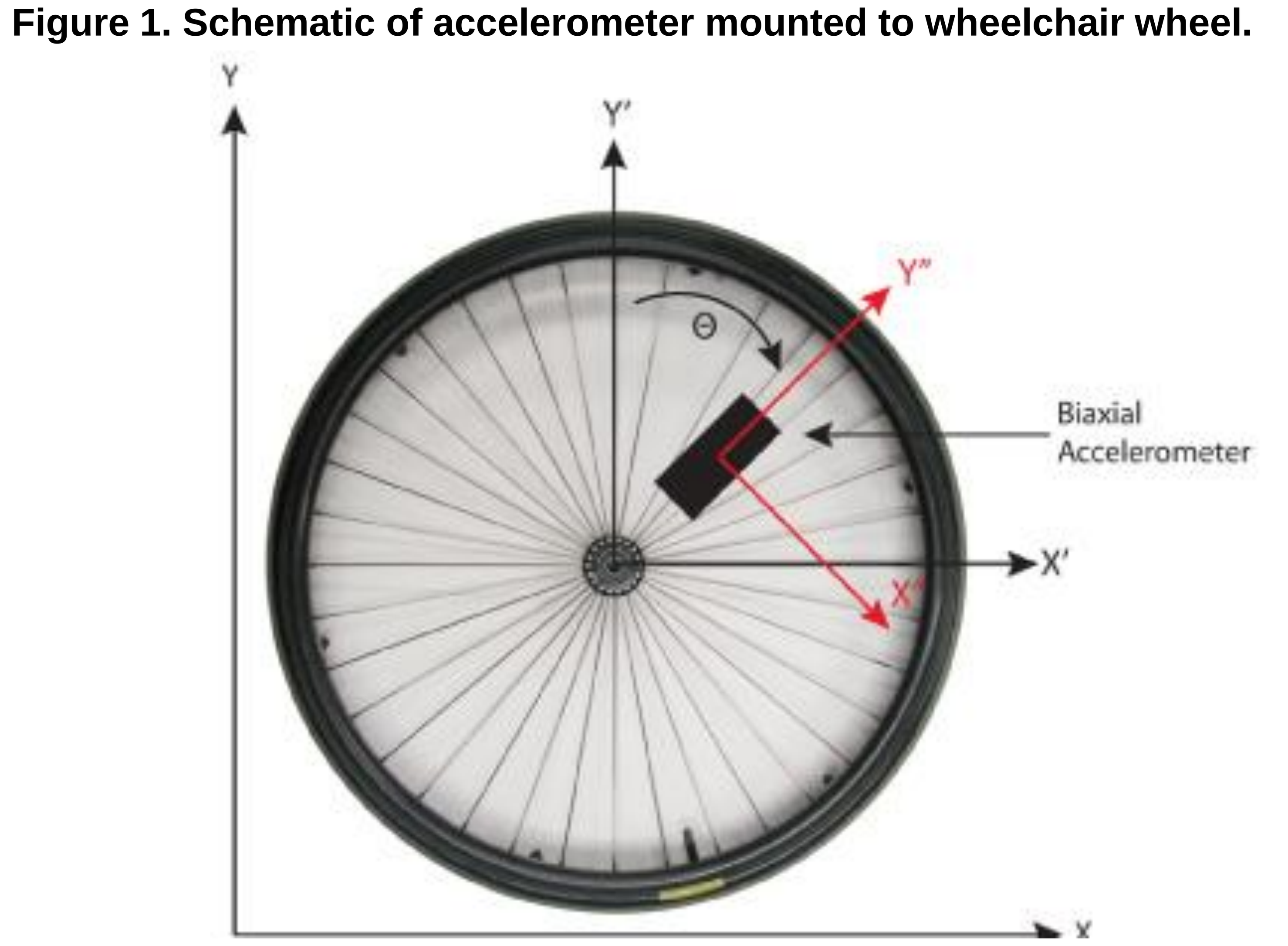
Practical

- Compatible with any wheel-mounted, bi-axial accelerometer
- Can individualize the analysis based upon specific project objectives

Performance

- Results should provide two data sets:
  1) a binary response to the question “is the wheelchair moving?”
  2) a continuous measure of distance wheeled.
- Accuracy should be ≥ 90% across different propulsion techniques (e.g. hand, foot), wheels (spoke, mag), and speeds.

Figure 1. Schematic of accelerometer mounted to wheelchair wheel.



ALGORITHM

Sampling Rate - based upon three factors: wheelchair speed, wheel size and precision of distance measurement. Tested 10 Hz and 60 Hz.

1. Low-Pass Filter Orthogonal, Uni-axial Accelerations
   - Used a 2nd order low-pass Butterworth filter with a 3.1 Hz cut-off (to include speeds up to twice the average walking speed, or 3 m/s)
   - Low frequency accelerations vary with orientation of wheel. (Figure 1 & Figure 2 – top)
2. Cumulative Revolutions
   - Unwrapped inverse tangent of the ratio of the two, orthogonal accelerations describes the wheel's orientation. (Figure 2 – middle)
3. Speed
   - The derivative of the cumulative revolutions (i.e., the angular speed of the wheel) was computed by taking the differences between consecutive data points and dividing by the sampling period. (Figure 2 – bottom)
4. Low-Pass Filter Derivatives
   - Used a 2nd order lowpass Butterworth filter with a 0.5Hz cut-off.
   - Filtered out accelerations from vehicles in which the wheelchair user was riding.
5. Movement
   - The absolute values of the speeds were compared to a threshold of 0.12m/s. Result of parameter search on test data with experienced wheelchair users and able-bodied participants wheeling indoors on hard surfaces at different speeds. The course included multiple starts, stops and turns. (Figure 2 – bottom)

TESTING AND VALIDATION

Indoor Obstacle Course – Test conditions included spoked and mag wheels, manual and foot propulsion, and fast and slow propulsion. The course incorporated both slow and aggressive starts, stops and turns over 30 meters of wheeling.

Indoor Activity-Based Movement – Test included 3 fulltime wheelchair users in their personal wheelchairs navigating tasks of daily living in typical environments (e.g. kitchen, bathroom, elevator, hallways) and an indoor obstacle course.

Outdoor Random Wheeling – Test used spoked and mag wheels in manual propulsion over concrete sidewalks, pavement and grass. In this test, the participants started and stopped as they wished; there was no planned course.

“Truth” Data - defined by a video camera aimed at the wheel.

Results – All tests had > 90% accuracy (Table 1)

RESULTS

Figure 2. Acceleration data and processing steps

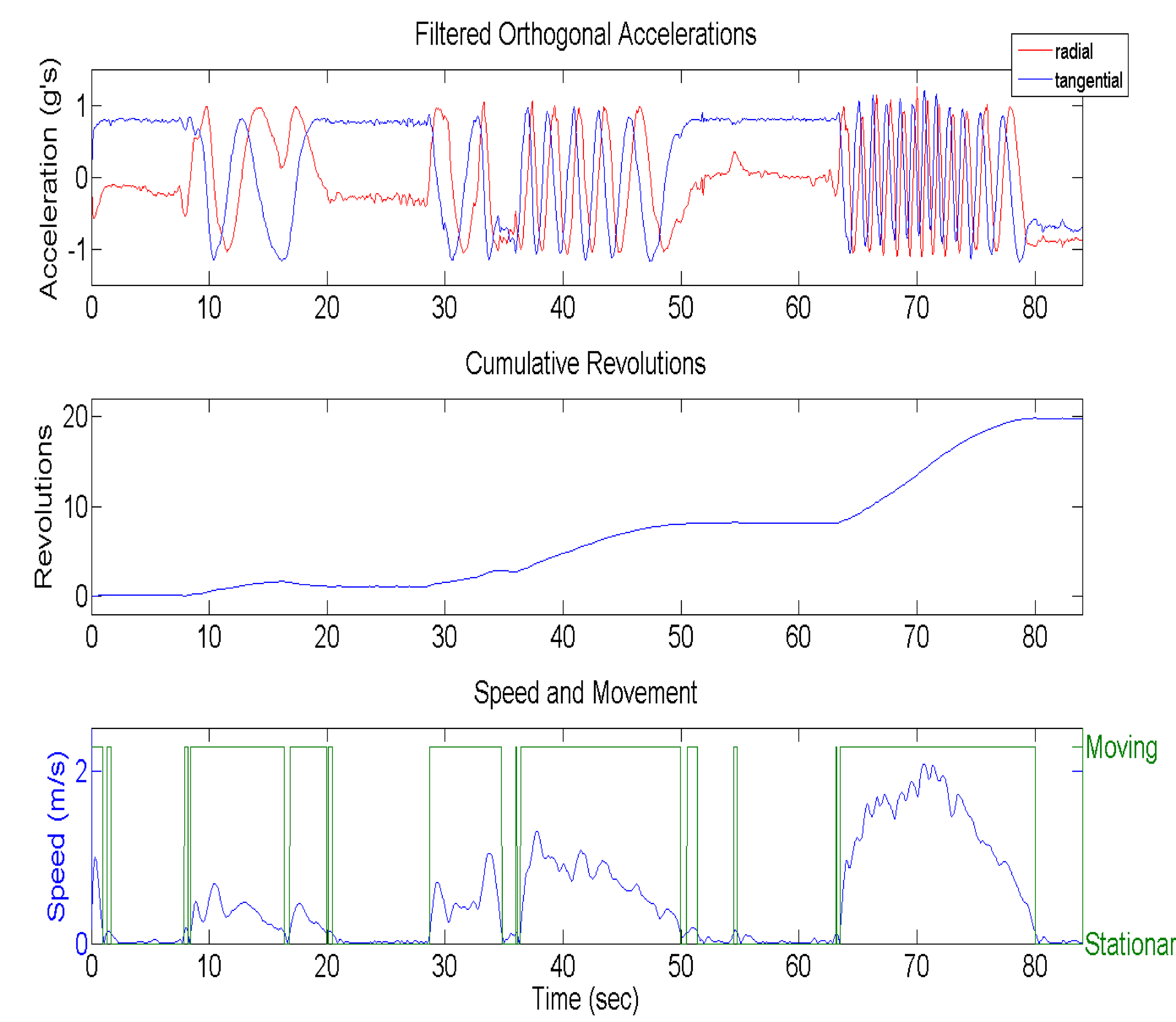


Table 1. Accuracy of wheelchair movement algorithm

	Point by Point Accuracy % (SD)	Total Time Accuracy % (SD)
Indoor Obstacle Course	91 (5)	91 (6)
Indoor Activity Based Movement - Moving	90 (6)	94 (5)
Indoor Activity Based Movement - Not Moving	95 (3)	93 (3)
Outdoor Random Wheeling	95 (2)	96 (2)

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